

“Augmented” Energiewende

Pumped hydro and Nuclear
to electrify Germany better and faster

Simplicity – Maturity - Ruggedness

PART 2

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Where is the Energiewende heading towards

A look at the current system and at its expected realistic evolution, based on the German government and industry's assumptions

The TerraWater Institute: modelling the low carbon energy transition

What the TerraWater Scenario for Germany AIMS FOR

- Satisfy Germany's energy requirements
- From the present state to the future
- While preserving,
 - climate
 - environment
 - democratic principles of self determination
 - For people (citizens' choices)
 - For states (sovereignty)
- In a challenging environment
- Without technological bias

What the TerraWater Scenario for Germany IS

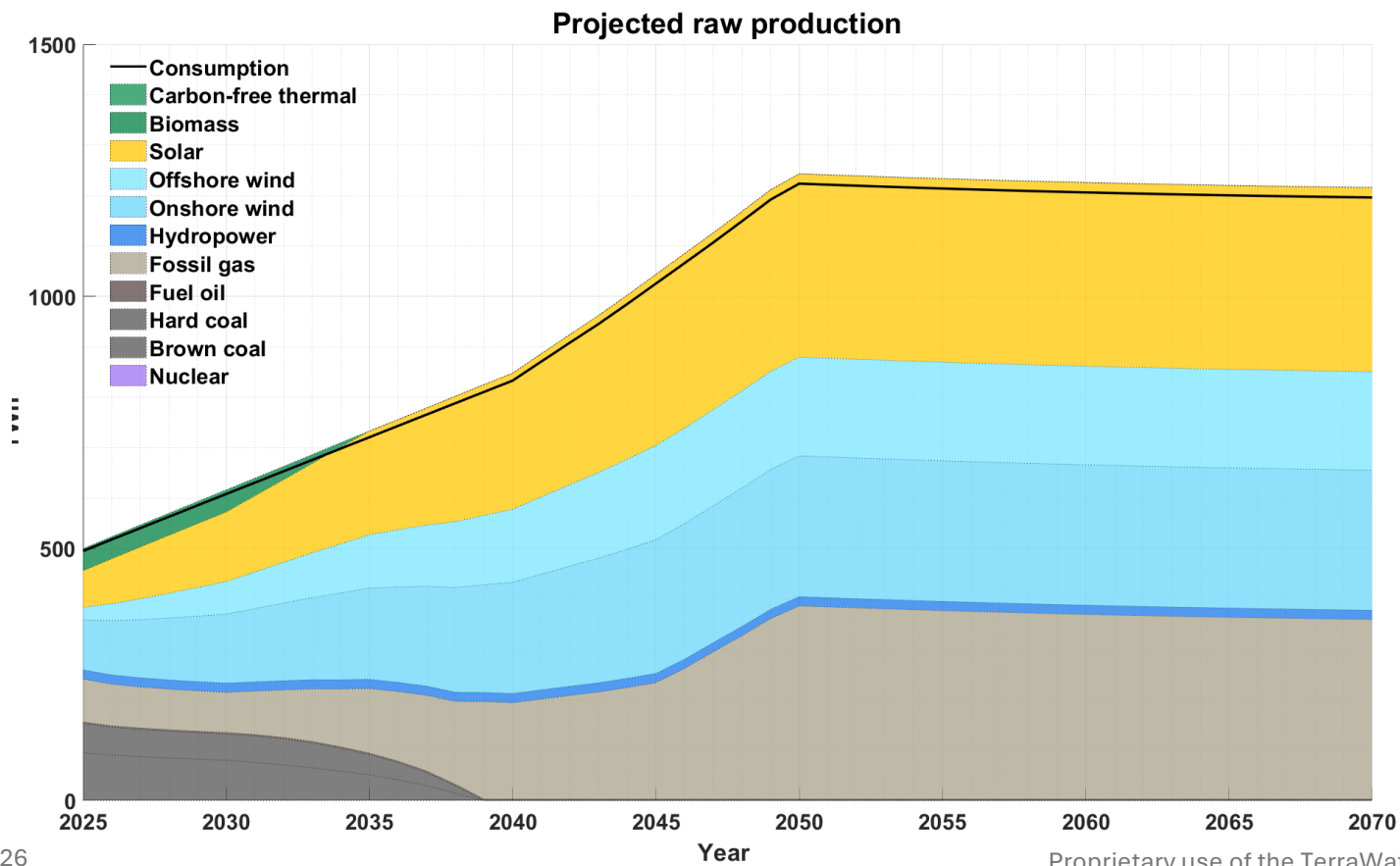
- Cautious
- Simple
- Robust
- Efficient
- Self-sufficient
- From a brownfield approach
- An Energiewende re-interpretation

...and what it IS NOT

- Unrealistically optimistic
- Anti renewable
- Full nuclear
- An ode to H2 or biomass

Energiewende deployment' targets can not provide enough energy to meet the demand induced by electrification

→ it would lead to an increased generation of fossil fuel power



Aligning rising electricity demand with decarbonization pathways will necessitate a huge effort

→ involving sobriety, interconnexions, and nuclear

- There is a **300 TWh/year gap** that is impossible to fill thanks to one vector only
 - **150 TWh/year can be brought by NUCLEAR** by 2050.
 - 150 TWh/year
 - **75 TWh/year of electricity IMPORTS:** challenging but manageable. 150 TWh/year electricity imports from neighbouring countries would be an unrealistic bet (record exporter (France) average export is 50 TWh/year, up to 90 TWh/year punctually (2024)).
 - **75 TWh/year must be found in demand reduction – SOBRIETY :** not culturally popular concept in Germany for population as for industry but that could be nevertheless be a lever. For instance, such amount can be saved though a 10% reduction in both industrial production and road traffic.

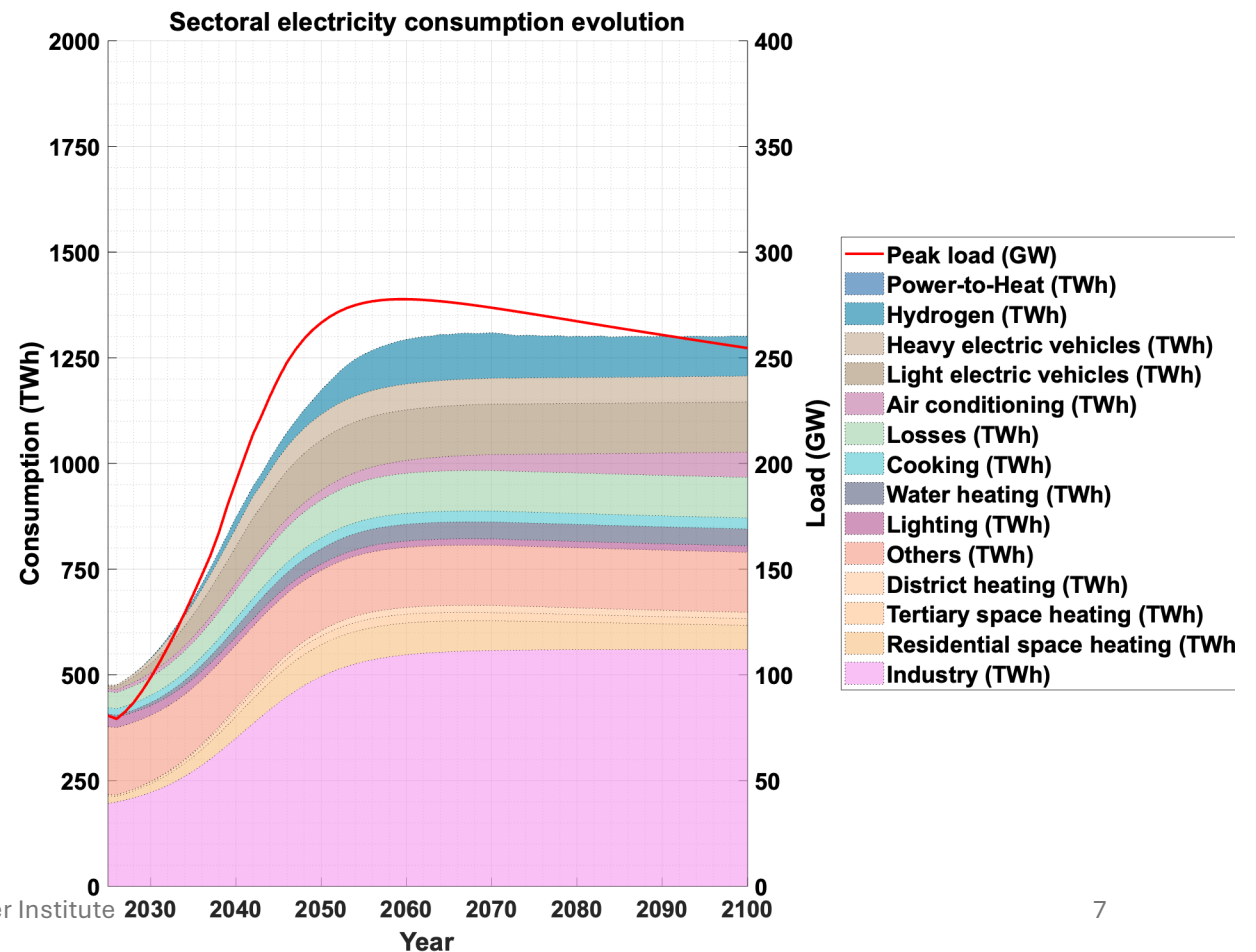
What exists in Energiewende and that we propose to keep

The official Energiewende makes many good choices.

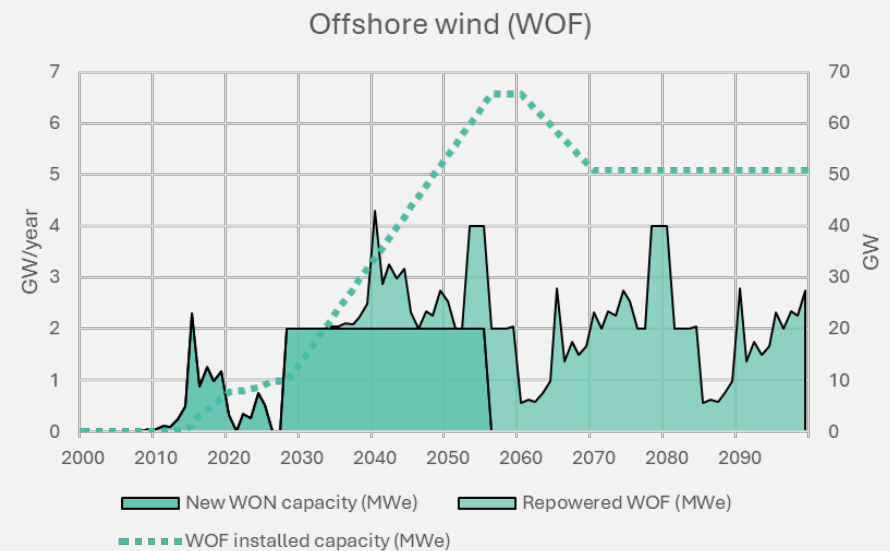
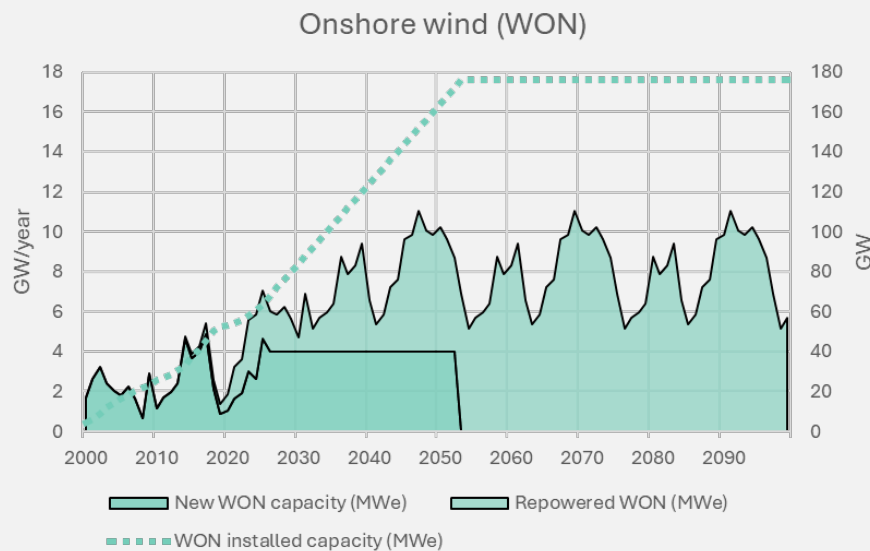
However insufficient for the scale of the country's needs, they should be complemented.

Electrification is paramount for optimized efficiency and decarbonization

- **Industry** : by far the **main contributor**, requires reliable power
- **Building heating** : **small in energy** but a **considerable burden during winter**, and with **uncertain** efficiency gains
- **District heating** : to use the **waste heat of backup thermal power** plants when used
- **Water heating and electric vehicles**: **integrate static flexibility** to try making the best use out of abundant solar power



Wind to remain the largest power source in Germany...

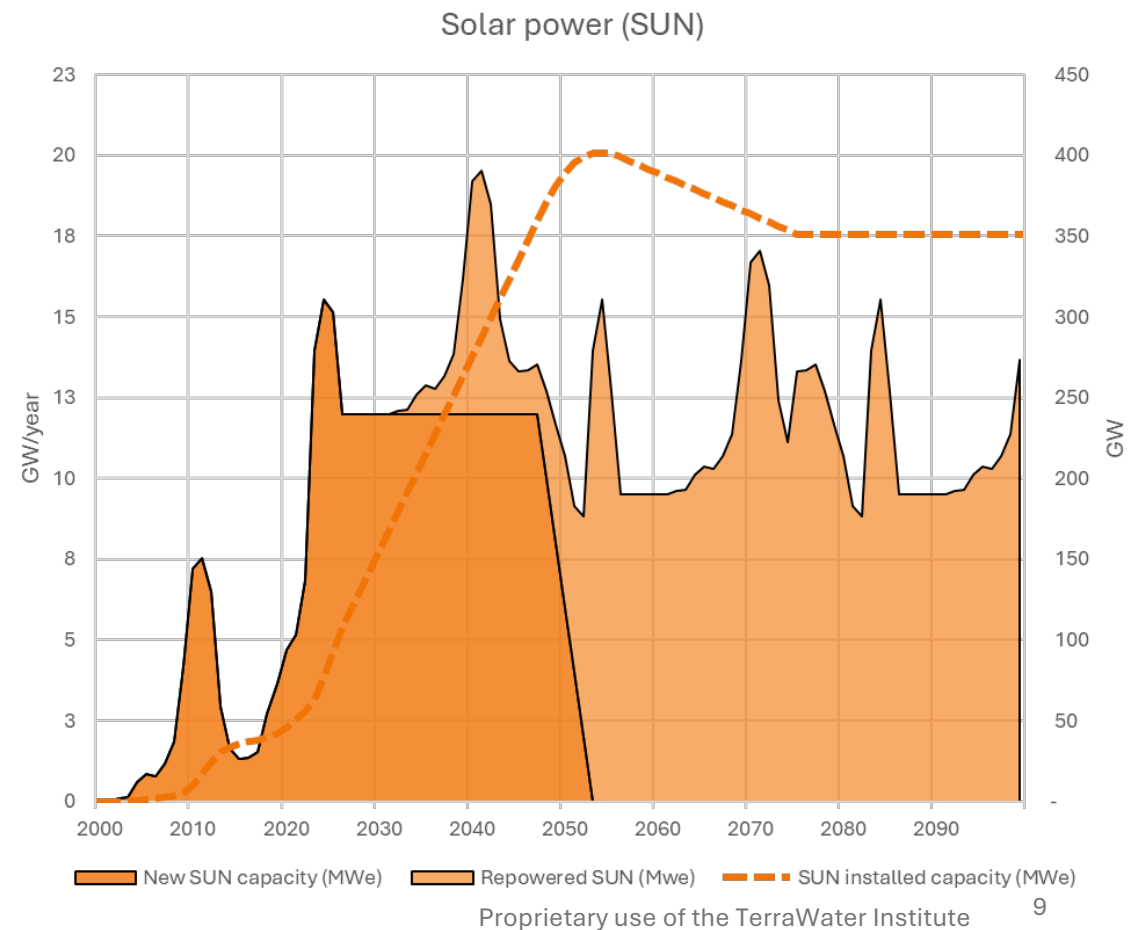


However,

- **Large uncertainty regarding the long-term capacity factor** evolution of Onshore wind, observable facts
- Reaching the 30% capacity factor planned by the German government is a **critical hypothesis**, currently not supported by
 - Offshore wind will show **saturation of the resource** in German waters

Solar projected share should be decreased to match seasonality

- Solar has a very **bad adequation between production and demand** when it comes to European seasonal consumption profile
- But **its ease of deployment** and **low gross cost** makes it nonetheless necessary.
- Actual replacement rate and capabilities of equipment will be key and to be looked after

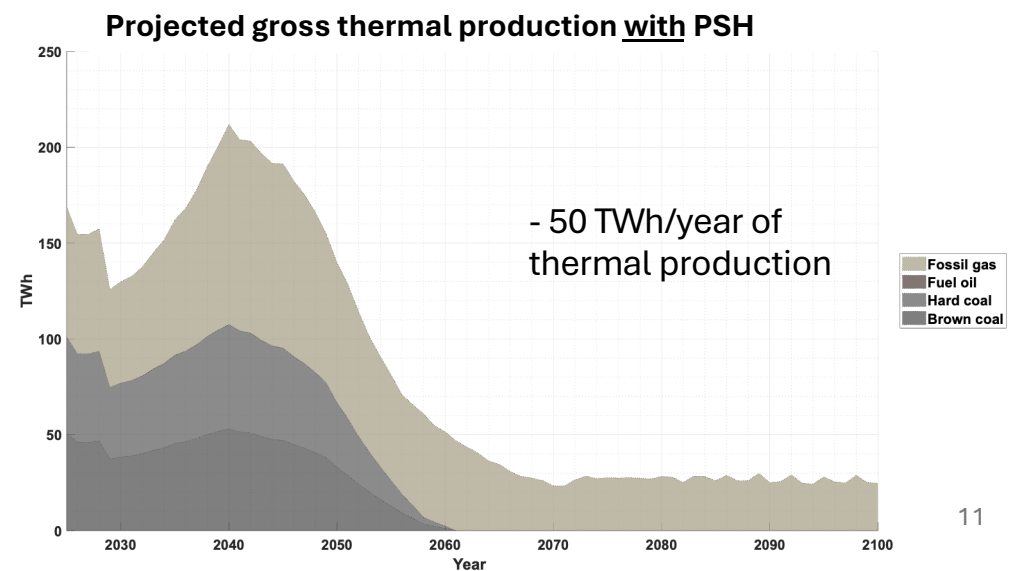
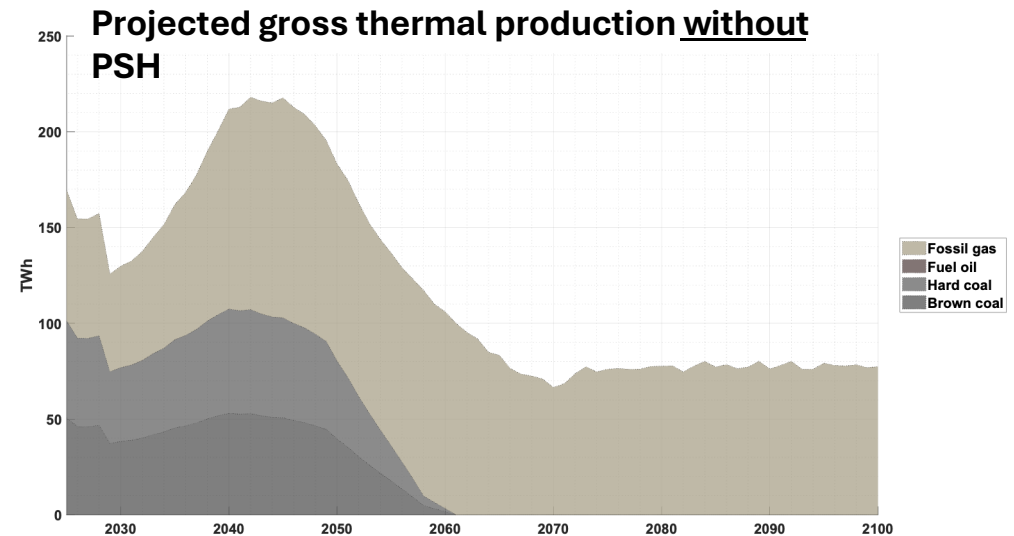


What the scenario adds to the Energiewende to help it reach its objectives

...which can be done even better with existing technologies

PUMP STORAGE HYDRO (PSH) BENEFITS

- Thermal backup capacity reduction in almost 1-per-1 ratio:
1 GW of long duration PSH reduces the need of gas plants by around 1 GW
- **+40GW of PSH → -40GW of gas plants**
 - (Germany will still need 140 GW of gas plants in 2055, and 100 GW in 2100...)
 - -50 TWh/year of thermal production
 - 2.5~5B€/year of fuel savings
 - Better use of the low carbon production



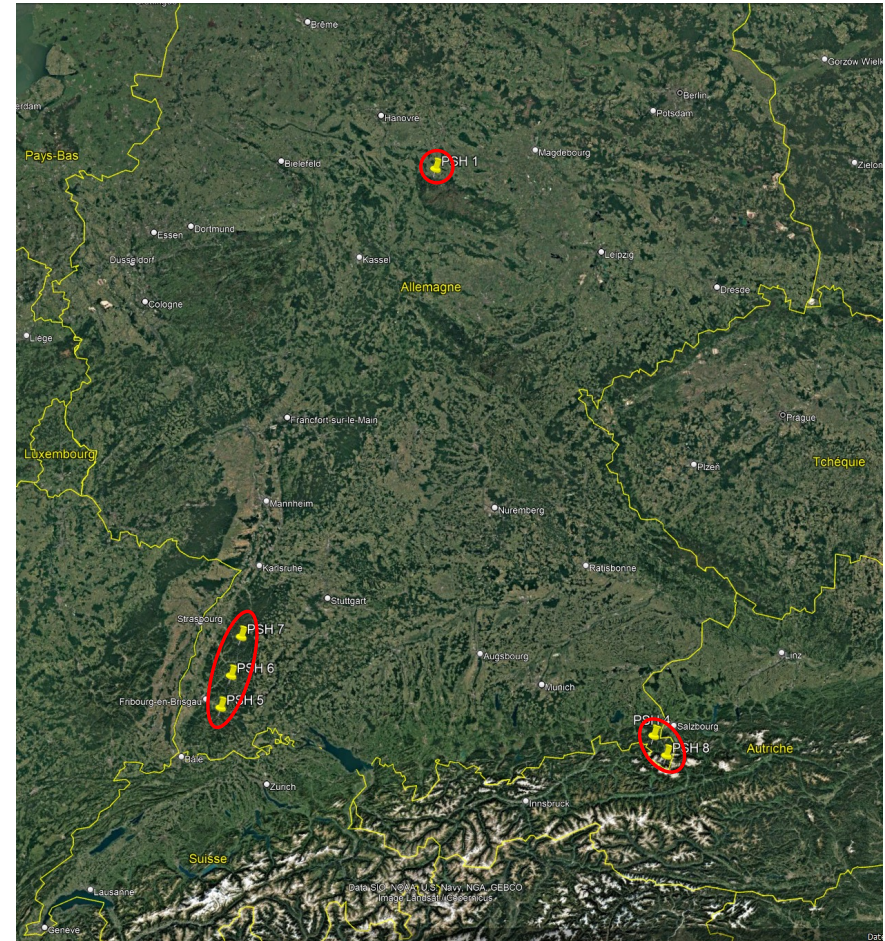
PUMP STORAGE HYDRO (PSH) PROPOSAL

A significant impact, but concentrated on a limited and identified number of people whose prejudice can be properly recognized and compensated

- Germany can develop **4000 GWh** with **relatively few resettlement**

(Higher potential found up to 12~13000 GWh but with many small cities flooded representing tens of thousand of resettled people),

- Simulation was conducted with **8000 GWh equipped with 40 GW**.
- Main sites are clustered in three areas: the **Harz Mountains**, the **Black Forest** and the **German/Austrian Alps**



With fewer sacrifices than the ones made for coal, Germany can develop a large PSH fleet

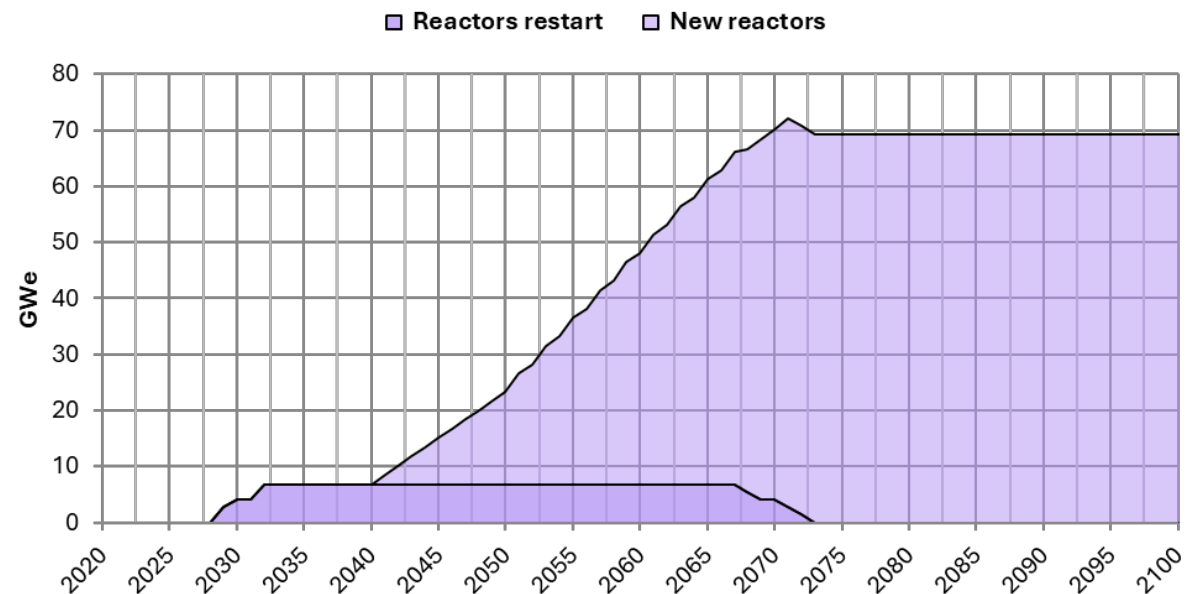
- Coal mines expansion has required the **resettlement of 70.000 people** in Germany, and **flattened 1800 km²**
- Coal industry killed around **5000 people a year** due to air pollution (20 deaths/TWh)
- The German people have proven able to commit to **nation-wide infrastructure deployment**



A third of nuclear in the German electricity mix (equ. pre-2011) is enough to bring considerable gains to the German power grid

- This is a pre-2011 “German-type” scenario
- 1st priority : **restart the five recently closed reactors** (KBR, KKE, KWG, GKN2, KKI2)
- 2nd priority : build new reactors in series from 2040 up to 2070 at a **regular deployment rate**
- Benefits on the reduction of fossil backup capacity are already major with **a nuclear share close to what it was in 2002.**

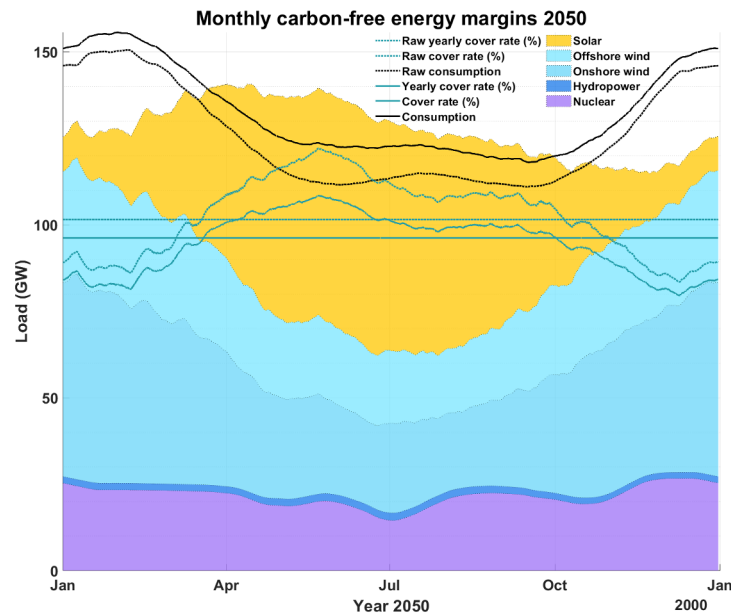
Nuclear active capacity (NUC)



Nuclear flexibility relies mostly on its unique capability to chose the shape of the seasonal availability curve

Little to no nuclear

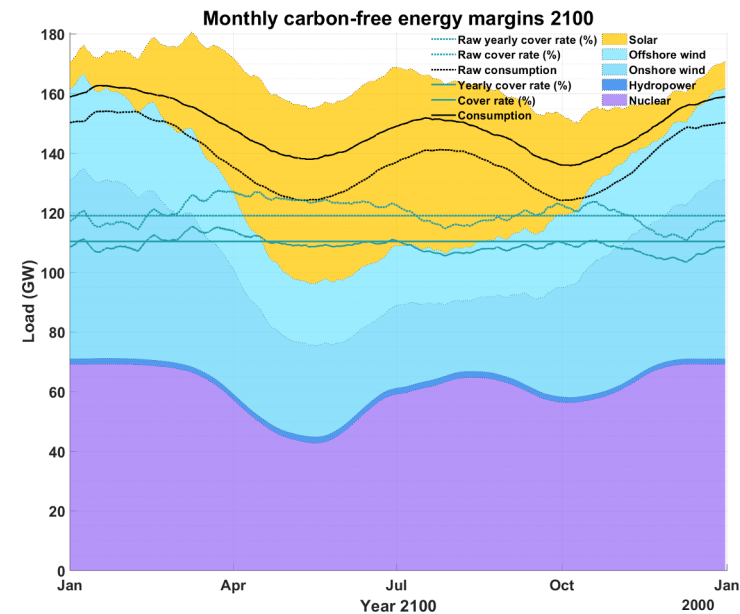
→ **Very unbalanced global mix** with massive deficit during the winter



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More nuclear

→ **More latitude to integrate solar** despite its unfavourable seasonal curve



Proprietary use of the TerraWater Institute 15

Nuclear opens opportunity to provide district heating

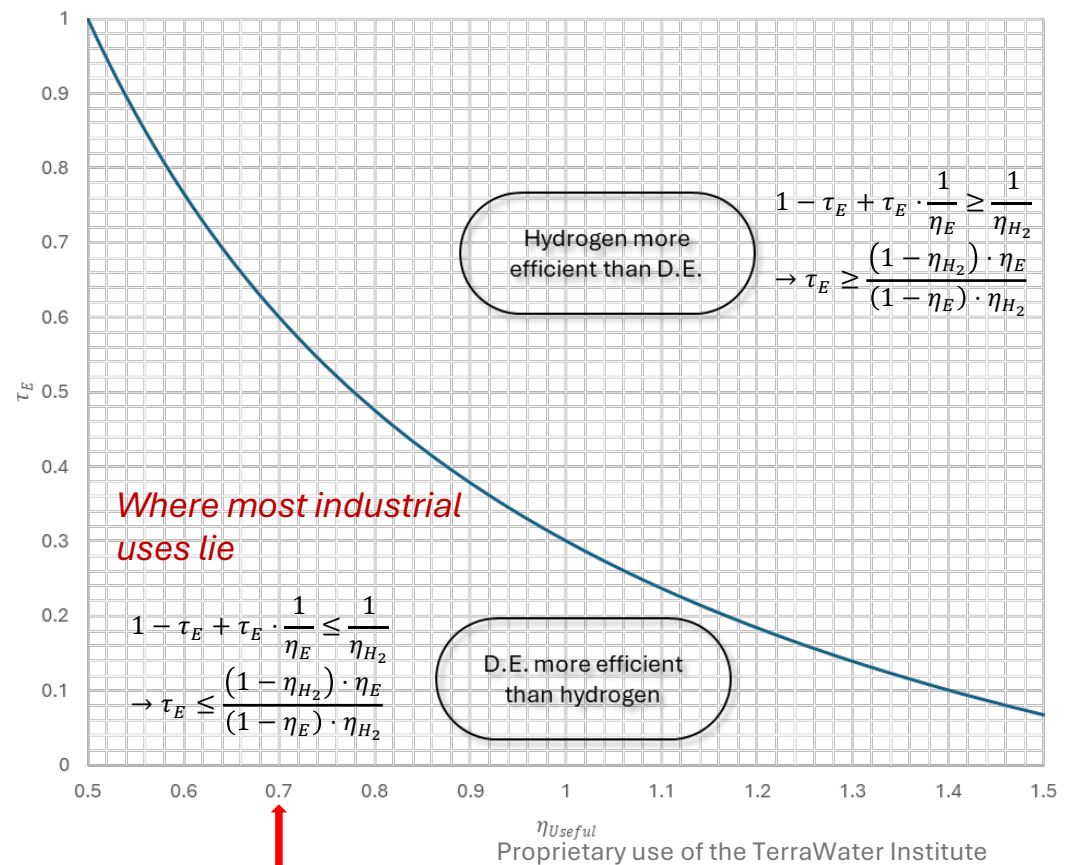
- **Decoupling of** heat production in the summer, from heat consumption in the winter,
- **Allows the integration of even more solar** by diverting several GW of nuclear, from electricity to heat, during the summer.



“H₂-be or H_{not-2}-be”

Germany should switch strategy from H₂ to Direct Electrification

- Germany plans **massive H₂ use** across industry
- But direct electrification brings a **30% final and 60% primary energy requirement reduction**
- Despite P2G2P poor roundtrip efficiency, **direct electrification brings lower consumption** even with a variable mix

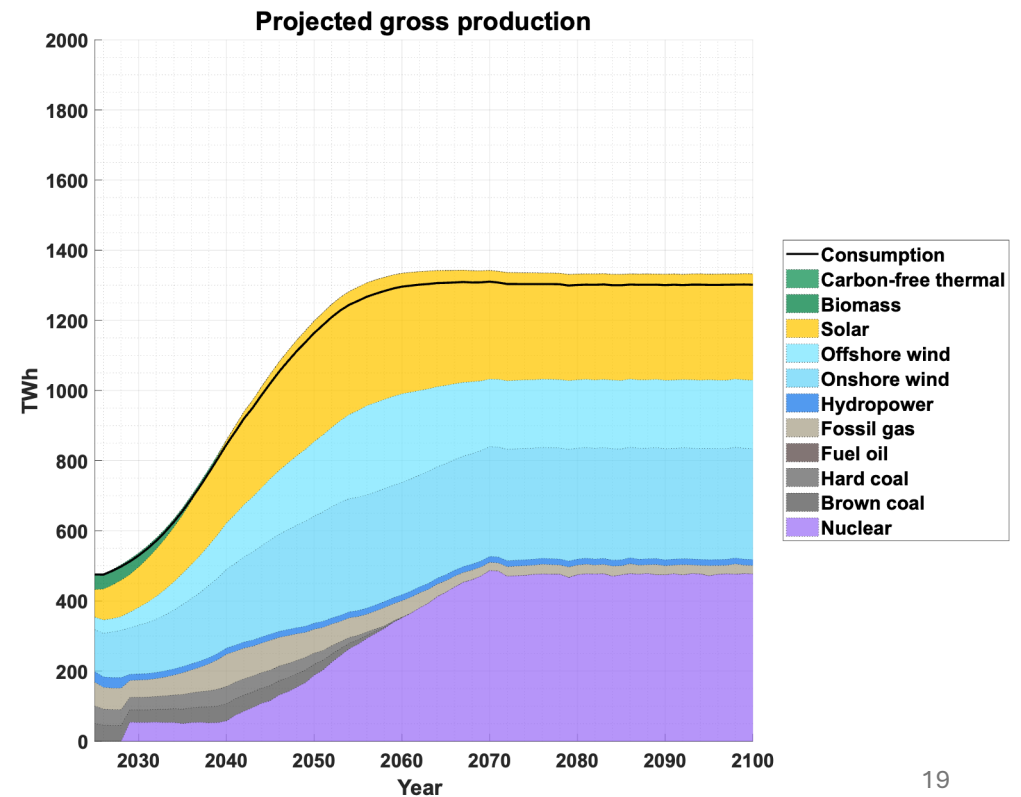


“Augmented Energiewende” – a TerraWater scenario for Germany

Results achieved

→ Search for optimal electricity generation leads to what the German Energiewende would be today without the Atomausstieg

- **Wind:** 510 TWh - 38%
 - **Solar:** 305 TWh - 23%
- } 61%
- **Nuclear:** 475 TWh - 35%
 - **Hydropower:** 17 TWh - 1%
 - **Thermal:** 25 TWh - 2%
(can still be reduced to ~17 TWh with iron electrolysis flexibility)



→ Decarbonization of German industry, with no sobriety effort required

“Fully Electric Germany is Efficient Germany”

- with
 - the same amount of consumed power as currently planned
 - cheaper
- without
 - Hydrogen imports
 - electricity net imports
 - Biofuels (saving them for non-energy uses and synthetic fuels)

Firming of the mix

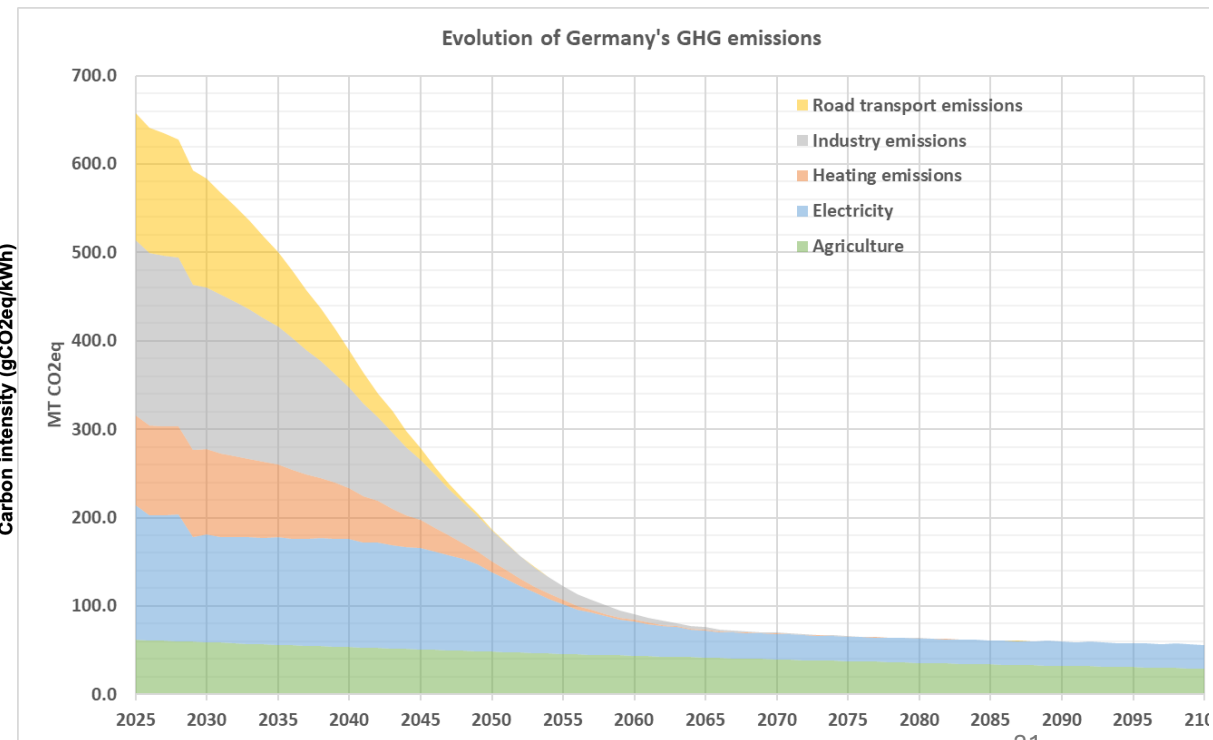
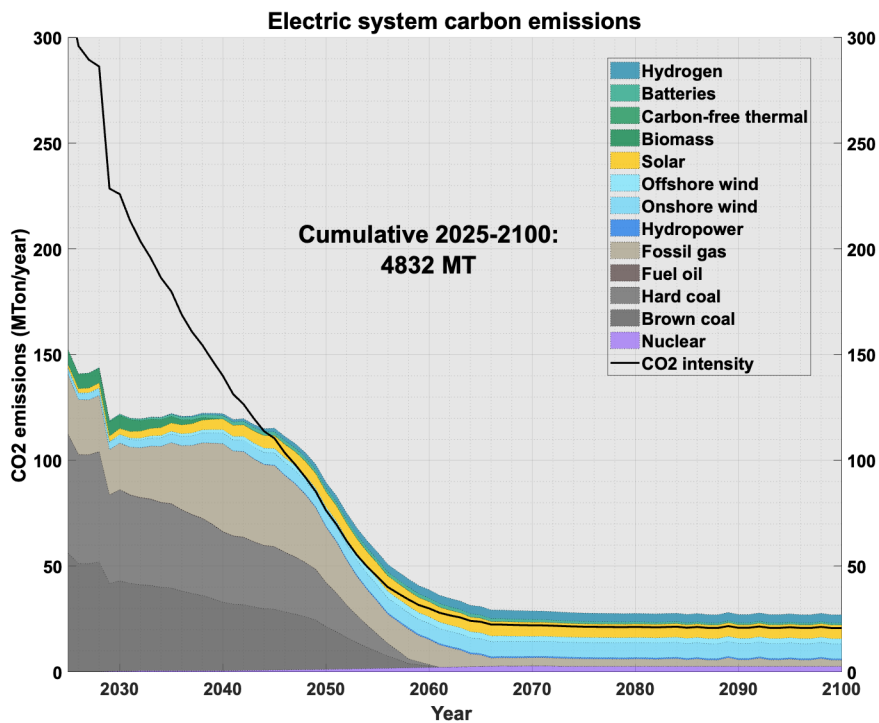
(thanks to pumped-hydro and nuclear)

+ more advanced electrification

= a much more efficient system

→ Total decarbonization by the 2060s

- Carbon intensity to reach of 100g/kWh by 2047, and 50g/kWh by 2054
- Coal power plants converted to gas, to dampen gas turbine shortage while still phasing-out of coal
- 90% of the decarbonization work achieved by 2055, over by 2060
- 2°C carbon budget exhausted, but not busted



- ➔ Back to German excellence, sovereignty and leadership as nuclear manufacturer
- ➔ Net contributor to European values, prosperity, and objectives

German nuclear industry designed and built nearly every single nuclear reactor in the country and even exported to other countries

This legacy still exists and should be restarted to support Europe's technological sovereignty.



Appendices

Appendix 1

German TerraWater Scenario – in Focus

Offshore Wind: associated benefits to be confirmed (1/2)

The expected increase in the wind fleet capacity factor claimed by wind industry remains to be demonstrated

Percentage full-load hours of offshore wind, onshore wind and solar
Years 2015–2025

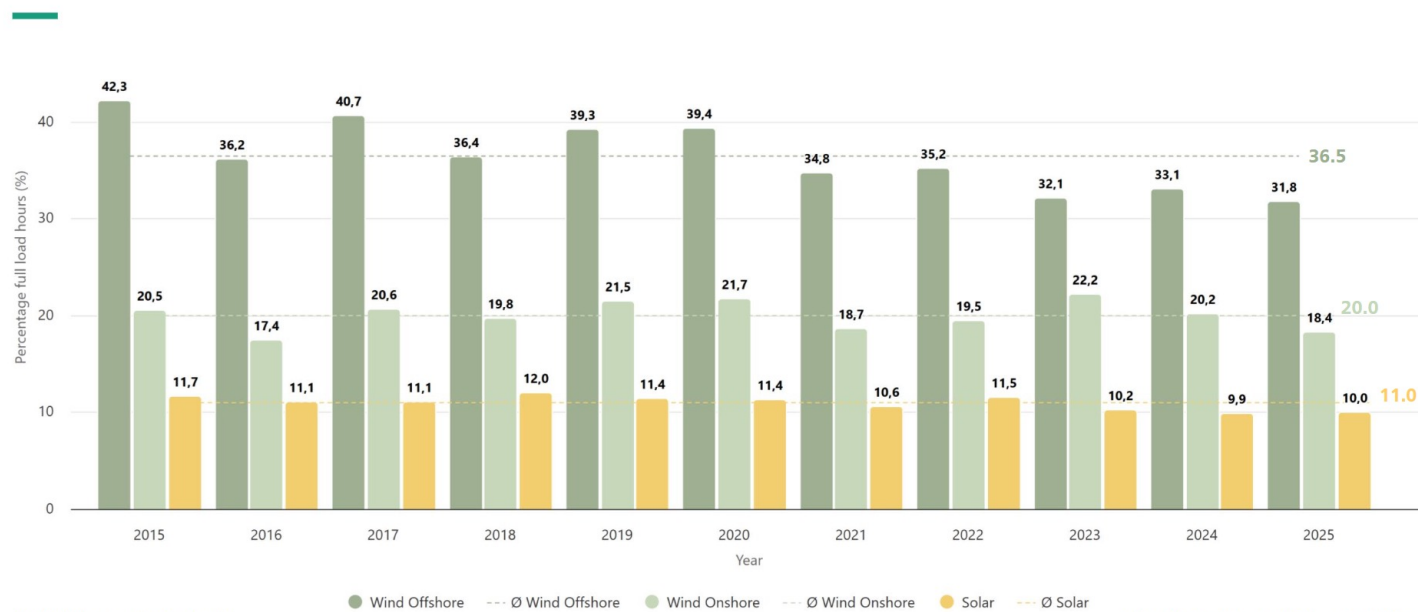


Chart: B. Burger, Fraunhofer ISE

*Data for total electricity generation

Offshore Wind: associated benefits to be confirmed (2/2)

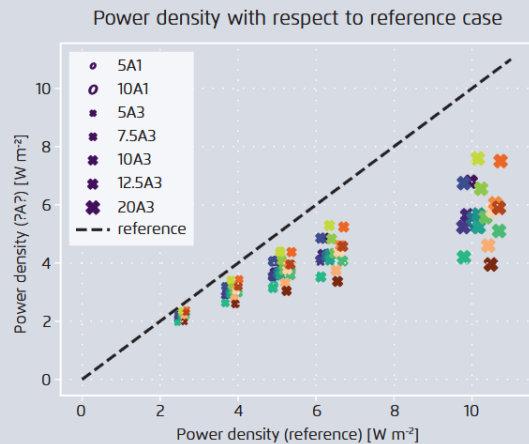
Offshore wind is also likely to be physically constrained

The more wind farms installed, the less efficient they become

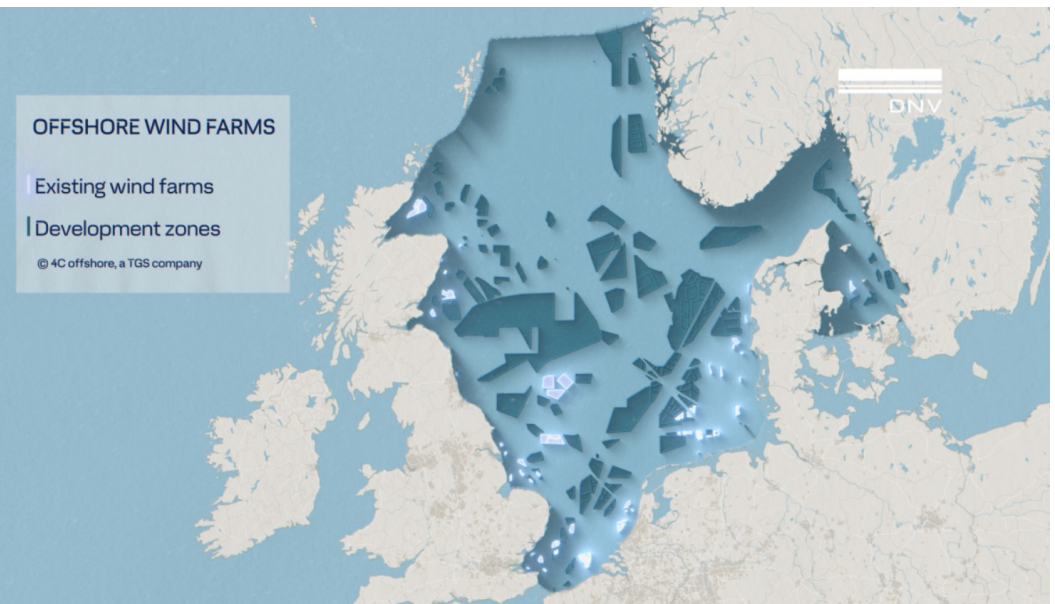
A phenomenon worsened by the presence of neighbouring countries farms

Modelled generated power density compared with nominal reference (no wake) power density in the different scenarios

Figure 19

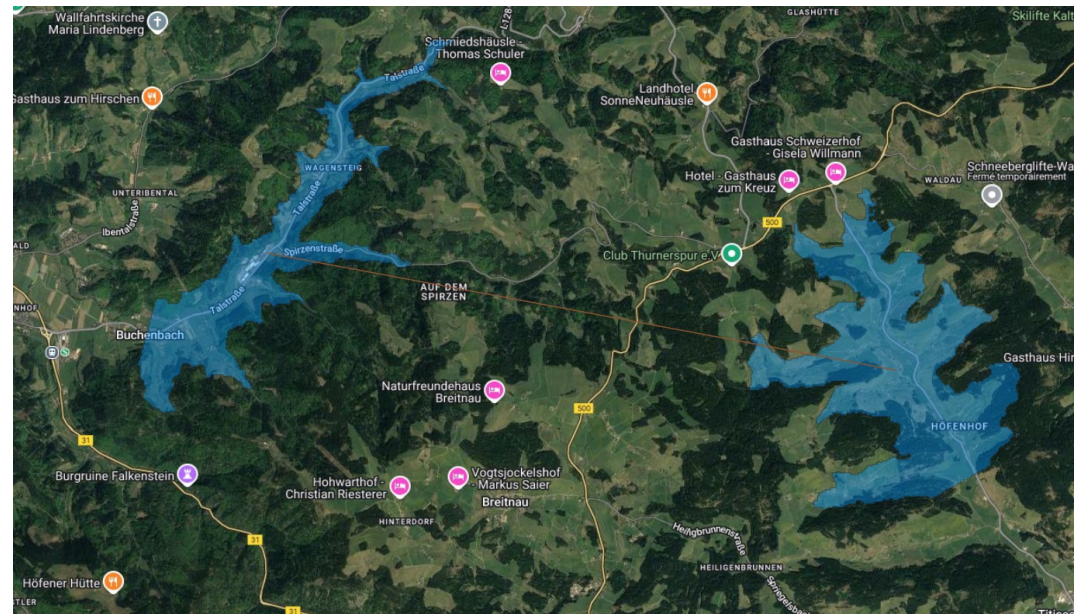
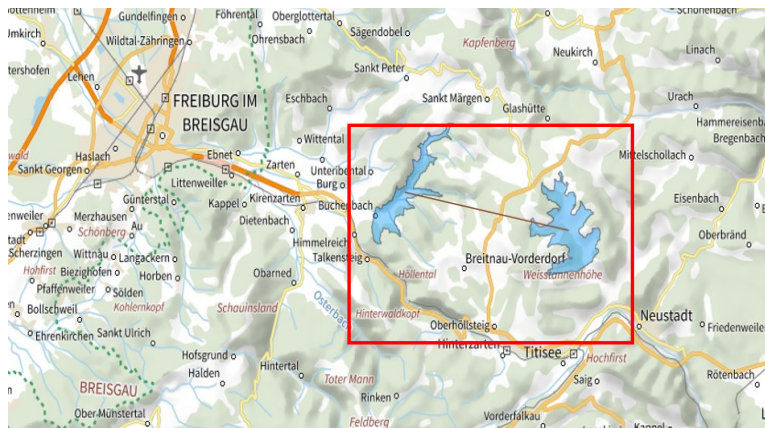


DTU (2020)



Pumped Storage Hydro : development is possible and should be encouraged (1/3)

Example of a PSH potential site identified by ActaPower on behalf of the TerraWater Institute



PSP characteristics		
Power (MW)		643
Storage Capacity GWh (400h)		257
Altitude of reservoir (meter)	Upper	990
	Lower	596
Volume of reservoir (hm ³)	Upper	383
	Lower	294

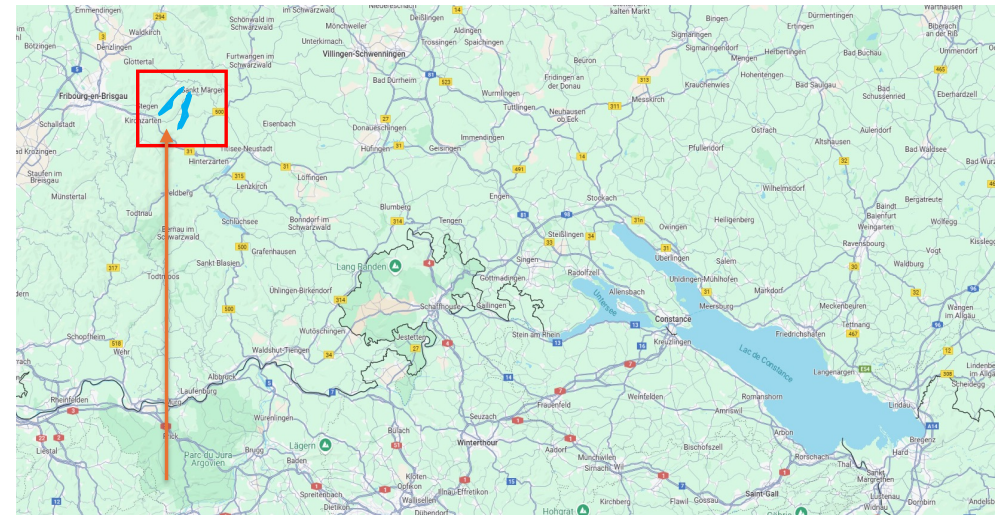
- This PSH would be located next to Freiburg. Less than 400 houses are located on the site
- In comparison, the Hambach mine relocated over 3,000 people and wiped 6 villages.

Pumped Storage Hydro : development is possible and should be encouraged (2/3)

More sustainable, durable, and resource-efficient solution for large-scale, long-duration energy storage than li-ion batteries

- Li-ion batteries require
 - large amounts of critical minerals (lithium, copper, graphite) creating supply chain risks and environmental pressure.
 - frequent replacement compared to technologies like PSP, because of typical service life of **10–15 years**.
- Li-ion systems are adapted for **short discharge times** (2–6 hours), making them inefficient and costly for storing energy over days or weeks.

Criteria	Pumped Hydro (STEP) 257 GWh	Lithium-Ion Batteries 257 GWh
Use of critical materials	None	Lithium, graphite, copper, etc.
Estimated lithium use	0	35,000 to 46,000 tons
Estimated copper use	Low (1,000–2,000 tons)	50,000 tons
Other key materials	Concrete, steel, copper (non-critical)	Cobalt*, nickel*, aluminium, graphite, steel
Recyclability	Very high (>90%)	Partial (<50%, especially for lithium/graphite)
Typical lifespan	60–80 years +	10–15 years
Supply chain exposure	Low (local, abundant materials)	High (dependent on China, DRC, global markets)



This 257 GWh PSP may seem large but it is

- small compared to Constance Lake
- smaller than a li-ion battery storage site of equivalent capacity²⁸

Pumped Storage Hydro : development is possible and should be encouraged (3/3)

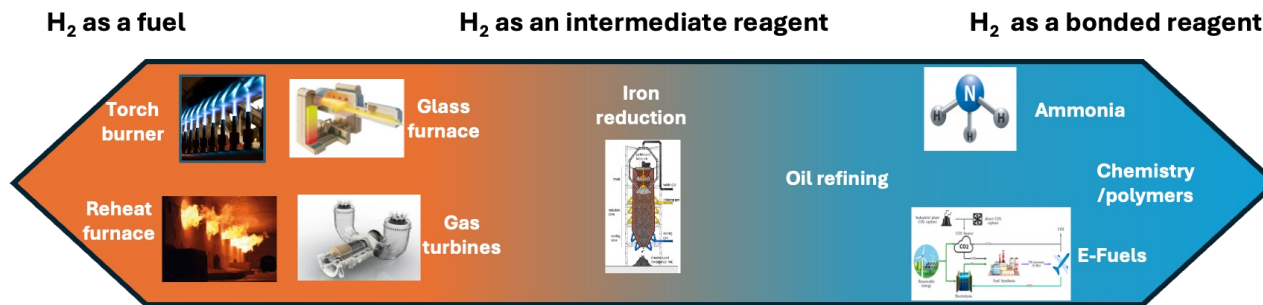
An extreme case



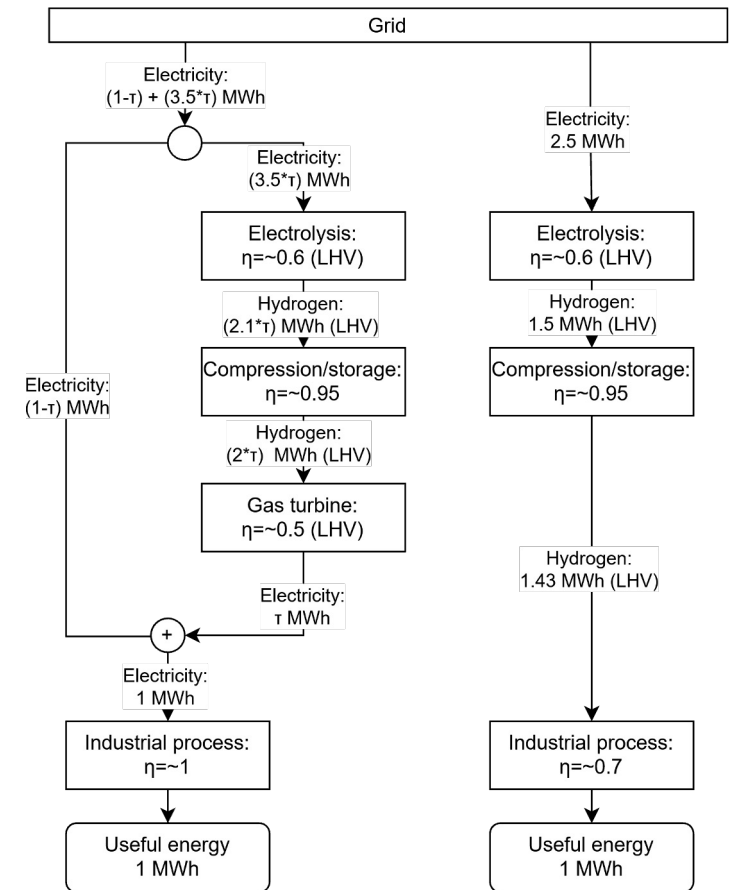
Site in the Black Forest
able to store 2000 GWh
of electricity.

Hydrogen use: “H₂-be or H_{not-2}-be” 1/2

Choosing between direct electrification (D.E.) and the use of H₂ for industrial uses



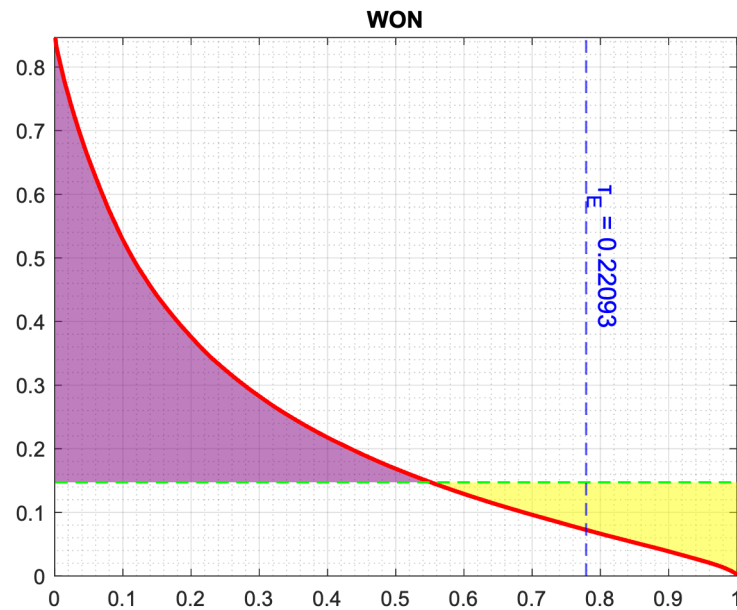
There exists a **competition between the use of H₂ and direct electrification** in the industrial sector due to the arbitrage between processes efficiency and energy supply flexibility.



Hydrogen use: “H_{2-be} or H_{not-2-be}” 2/2

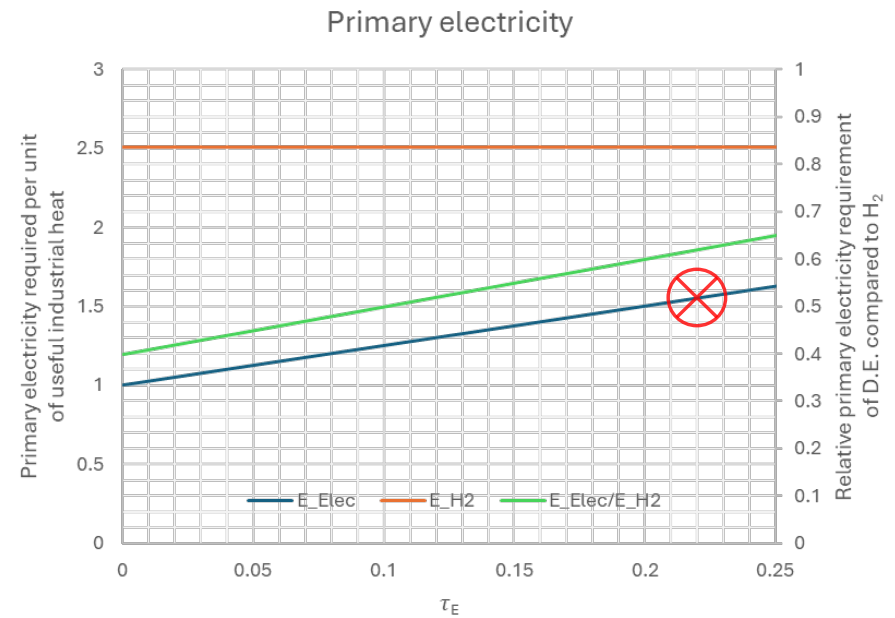
“DE should go D.E.”

The more puzzle pieces are integrated, the less hydrogen backup is required...



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...the less energy is required

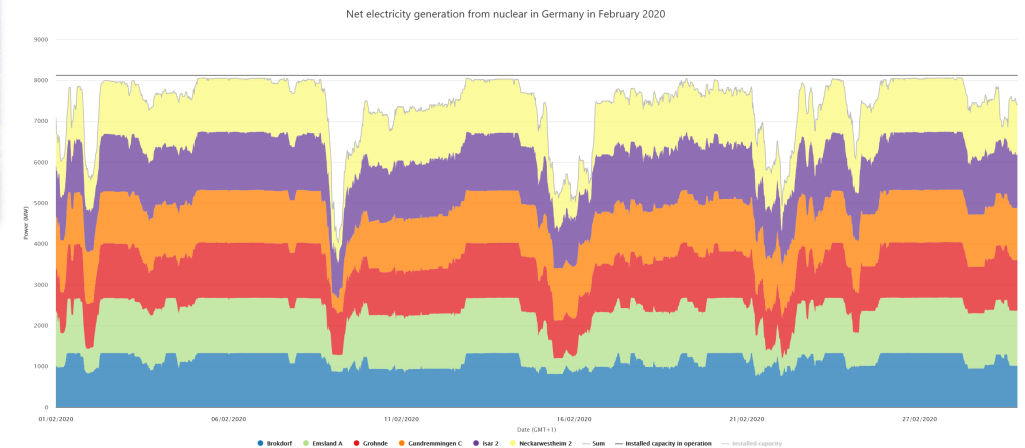


Proprietary use of the TerraWater Institute

Nuclear power plants flexibility

Every single German reactor was tested during commissioning with ramps up to 10%/min

In their last years of operation, German reactors showed very good flexibility capacities



- > Proof of load-following ability during the commissioning of the Emsland nuclear power plant
- > Maximum power ramp rate: 140 MW/min

Biomass: many uses but also a high environmental impact

To be reserved for mobile applications

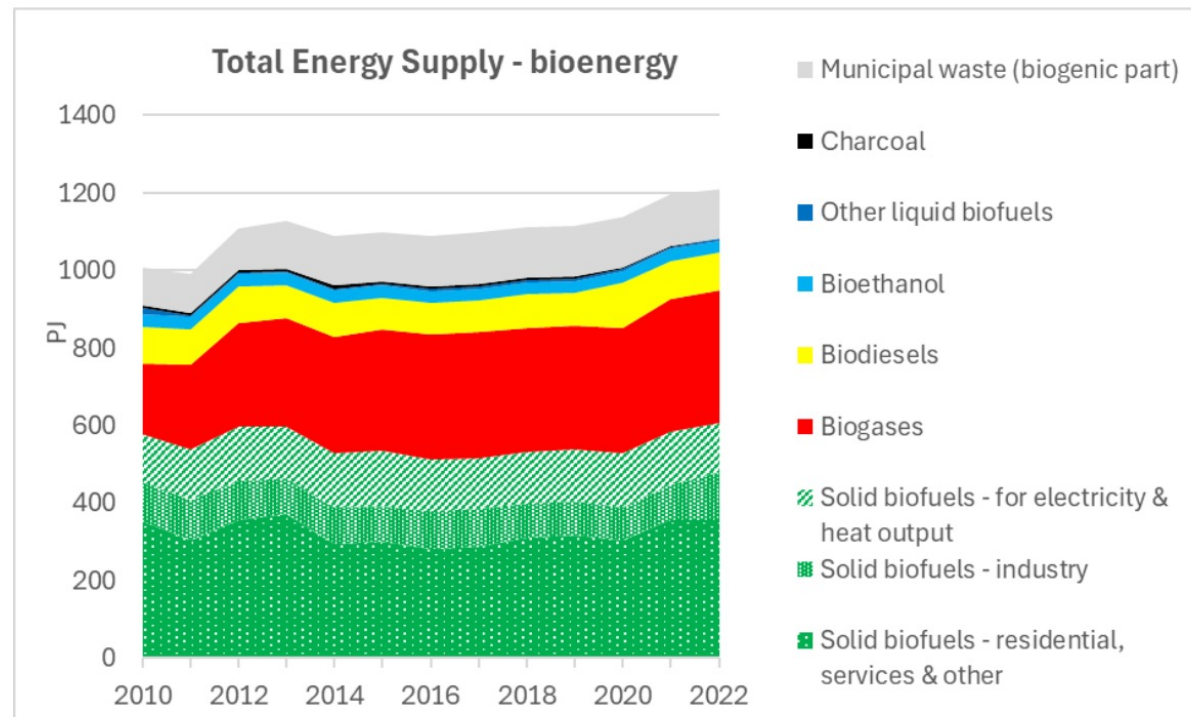


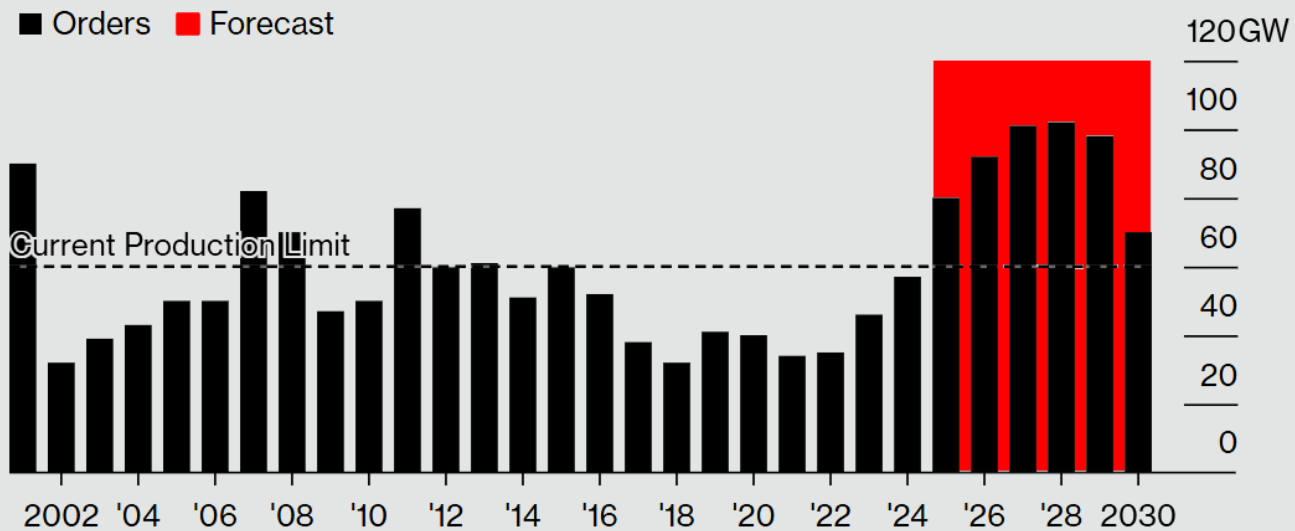
Figure 3: Development of total energy supply from bioenergy in Germany (data source: IEA (2024) World Energy Balances and Renewables Information)

Coal plants to be converted to gas plants

They will (unfortunately) still be needed

Gas Turbine Shortage

Orders for the power plant equipment are set to rise to the highest level in decades and outpace production capacity



Source: Barclays; Wood Mackenzie; IEA; Bloomberg News

Appendix 2

German Energiewende current status

(for full analysis refer to ATOM DAY 2025 TerraWater Institute' presentation of "TerraWater Scenario Germany Part 1")

Former Coalition’s Experts (2024) expose major gaps in 2030 climate target renewables share ≠ decarbonization share

Dimension	Sub-dimension	Indicator	
• Energy Supply	Electricity	• Evolution of absolute electricity generation from renewable energies (Chapter 2.3.1)	Green
		• Evolution of renewable electricity generation capacities (Chapter 2.2.1)	Yellow
		• Evolution of the share of renewables in gross electricity production (Chapter 3.2.1)	Green
	Final Energy Carrier	• Green hydrogen (Chapter 4.4)	Yellow
	Overview of the Energy Sector	• Evolution of the share of renewables in gross final energy consumption (Chapter 2.1)	Red
		• Evolution of final energy consumption (Chapter 2.1)	Red
• Security of Supply	Grids	• Development of the transmission network (Chapter 3.4.2)	Yellow
		• Digitization (Chapter 3.5.3)	Red
		• Implementation of congestion management measures (Chapter 3.4.3)	Red
	Dispatchable Power Plants	• SAIDI Electricity and SAIDI Gas (Chapters 6.1.4 and 6.2)	Green
		• Dispatchable power plants (Chapter 6.1)	Yellow
		• Battery storage capacity (Chapter 3.5.1)	Green
• Energy Security	Diversification	• Herfindahl index for natural gas (Chapter 6.2)	Red
	Access to Resources	• Non-energy resources relevant to supply (Chapter 6.3)	Red
• Affordability / Cost-effectiveness	Energy Efficiency	• Energy productivity (Chapter 2.1)	Green
		• Heat demand (Chapter 5.1)	Red
		• Energy efficiency in the residential sector (Chapter 5.1)	Red
	Energy Costs	• Share of household electricity costs in GDP per capita (Chapter 7.1)	Yellow
		• Energy costs for industry in Germany (Chapter 7.1)	Yellow
		• Average annual electricity expenditures of households (Chapter 7.1)	Yellow
		• Average electricity price for households (Chapter 7.1)	Yellow
• Environmental Compatibility	Greenhouse Gas Emissions	• Reduction of greenhouse gas emissions (Chapter 3.1)	Yellow
		• Phase-out of coal (Chapter 3.3)	Yellow
		• Deployment of heat pumps (Chapter 5.3)	Yellow
		• Share of electric vehicles (Chapter 3.1)	Red
• Societal Aspects	Acceptance	• General support for the energy transition goals (Chapter 8.2)	Green
		• Support for the implementation of the energy transition (Chapter 8.2)	Yellow
		• Perceived personal impact of the energy transition (Chapter 8.2)	Red
	Redistribution	• Energy equity (Chapter 8.1)	Red
		• Energy cost burden relative to household income (Chapter 8.1)	Yellow
		• Energy cost burden relative to total consumer spending (Chapter 8.1)	Yellow

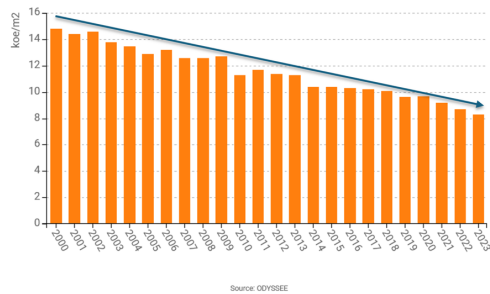
Germany is not organized around an energy efficient model

Germany's efforts to reduce energy consumption are either modest or inefficient

Building insulation seems to have stalled in Germany

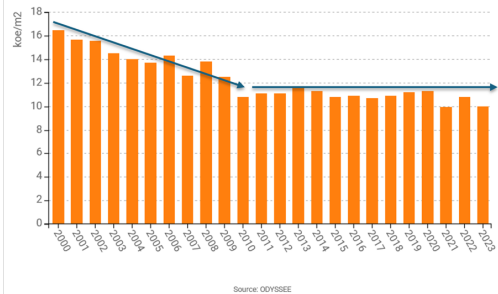
France

Figure 8: Energy consumption of household space heating per m2 (with climatic corrections)

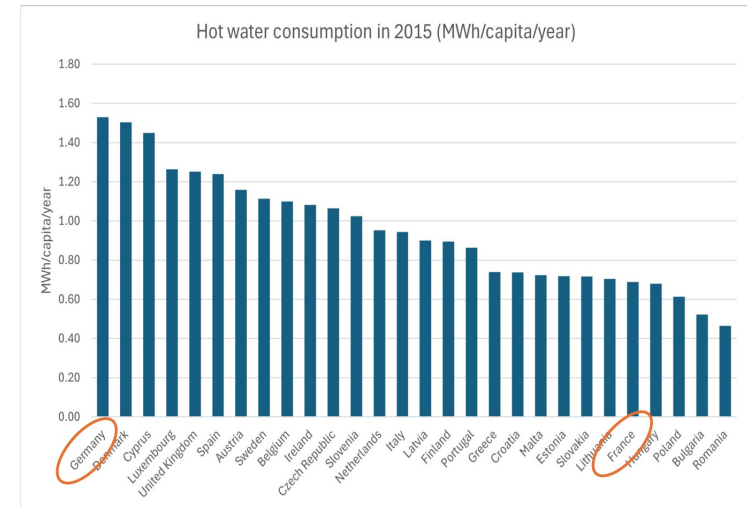


Germany

Figure 8: Energy consumption of household space heating per m2 (with climatic corrections)



Hot water consumption per capita in Germany x2 that of France



Germany's power sector contracted more >20% while it needs to double 240 000 industrial jobs lost in 2 years

